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Original Citation

Fabricatore, Carlo and López, Ximena (2014) Complexity-based learning and teaching: a case study in higher education. Innovations in Education and Teaching International, 51 (6). pp. 618-630. ISSN 1470-3297

Complexity-based learning and teaching: A case study in higher education

[Final draft post-refereeing]

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Please cite as:

Fabricatore, C., & López, M. X. (2014). Complexity-based learning and teaching: a case study in higher education. Innovations in Education and Teaching International, 51(6), 618–630. doi:10.1080/14703297.2013.829408

Link to publisher version:
http://www.tandfonline.com/doi/abs/10.1080/14703297.2013.829408#.UzMPpvl_uvA

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Complexity-based Learning and Teaching: A Case Study in Higher Education

Abstract

This paper presents a learning and teaching strategy based on complexity science and explores its impacts on a higher education game design course. The strategy aimed at generating conditions fostering individual and collective learning in educational complex adaptive systems, and led the design of the course through an iterative and adaptive process informed by evidence emerging from course dynamics. The data collected indicate that collaboration was initially challenging for students, but collective learning emerged as the course developed, positively affecting individual and team performance. Even though challenged, students felt highly motivated and enjoyed working on course activities. Their perception of progress and expertise were always high, and academic performance was on average very good. The strategy fostered collaboration, and allowed students and tutors to deal with complex situations requiring adaptation.

Keywords: complexity, learning and teaching strategies, complex adaptive systems, higher education, adaptive process

Introduction

The influence of complex systems on our living is closer and more direct than ever before. The challenges and importance of dealing with salient traits of complexity such as change, self-adaptation, unpredictability and emergence, are broadly acknowledged in diverse contexts, including sustainability, business management and education (e.g. McDaniel & Driebe, 2005; Davis & Sumara, 2006; Helbing & Lämmer, 2008; Patton, 2010).

Diverse perspectives adopted in these contexts converge on the need of proper “complexivist mindsets” to cope with complexity. In order to prepare individuals for an increasingly complex and intertwined world, contemporary education should foster the ability to adapt to change, to understand phenomena in context, to face ill-defined situations and to work in collaboration with others who may not share ideas or interests (Davis & Sumara, 2005, 2006; Frei, 2011).

Developing educational strategies which foster these skills is far from simple. Although practical advice has been provided (Davis & Sumara, 2006), there is still little research analysing concrete experiences. This paper aims at presenting a complexity-based educational strategy exploring its impacts in a higher education course.

Complexity in education

The course as a complex system

Complexity research indicates that learning and education are complex phenomena, and that educational systems can be regarded as complex adaptive systems - CAS (Davis & Sumara, 2005, 2006; Morrison, 2006; Frei, 2011). CAS are:

> (…) dynamical and emergent, sometimes unpredictable, non-linear organizations operating in unpredictable and changing external environments (…) [They] adapt to macro- and micro-societal change, and, through self-organization, respond to, and shape the environments of which they are a part. (Morrison, 2006, p. 3).

CAS evolve through self-organised interaction dynamics among system agents adapting to external changes (Davis & Sumara, 2006). This leads to the phenomenon of emergence, whereby '(…) well-formulated aggregate behaviour arises from local behaviour' (Miller and Page, 2007, p. 46). Without the intervention of a centralized control, emergence originates new, unpredictable patterns of system organization which cannot be fully explained through properties of the system's constituent parts (McDaniel & Driebe, 2005; Miller & Page, 2007; Patton, 2010). CAS self-organized adaptive evolution can be considered the outcome of events of learning which engender transformations leading to different forms of the same system. Hence, CAS (including educational systems) can be considered proper learning systems (Davis & Sumara, 2006; Newell, 2008).

A higher education course is a specific instance of educational system. Therefore, it can be regarded as a complex system (Frei, 2011). However, features and dynamics of contemporary education, including a fragmented curriculum, radically individualised and imposed evaluations, limited time and overload of administrative work, often lead educators to adopt instructional approaches and course management strategies that centralise control and information in the teacher's hands, and hinder collective learning, self-organization and emergence (Fuite, 2005).

Why a complexity-based educational strategy

The perspective of complexity management

Complexity management research indicates that CAS system dynamics cannot be governed recurring to centralised decision-making and control (e.g. Helbing & Lämmer, 2008; Kempf, 2008). CAS require management approaches focused on supporting and guiding natural self-organization processes through understanding and making use of natural system tendencies and behaviours. These ideas promote the adoption of complexity-based educational strategies to design courses relying on continuous iterative cycles of planning, acting, assessment of results and consequent revision of plans and/or assumptions, building upon emerging evidence (Argyris, 1977).

The perspective of educational outcomes

From a complexity perspective cognition is regarded as an on-going process of adaptive activities involving isolated or coupled agents (Davis & Sumara, 2005, 2006; Newell, 2008). Within a given system learning is a trans-level process, happening both at the level of individuals and whole collectives regarded as proper learning entities (Davis & Sumara, 2005, 2006; Miller & Page, 2007; Newell, 2008). The interplay of individual understandings and knowledge originates collective learning which transcends individual learning and reshapes the system as a whole. Emerging collective learning, in turn, feeds back into individual learning, enhancing it beyond what could be achieved by individuals alone (Davis & Sumara, 2005, 2006; Newell, 2008). Thus, in CAS individual learning evolves adapting to collective learning, and vice-versa. Therefore, disregarding the importance of collective learning confines the development of individuals within the boundaries of what is afforded by compartmentalised individual learning. Only through complexity-based educational strategies it is possible to fully leverage the interplay between individual and collective learning (Davis & Sumara, 2006; Frei, 2011).

Student heterogeneity is another important reason to promote complexity-based educational approaches. Adaptive and iterative strategies are best suited to create courses supporting different learning styles and levels of skills as they emerge from the learning processes (Mainemelis, Boyatzis & Kolb, 2002).

Finally, complexity-based strategies contribute to preparing individuals for an increasingly complex and intertwined world. Barnett and Hallam (1999) indicate that the world has entered an age of “Supercomplexity”, characterised the existence of multiple frameworks to interpretation. Consequently, knowledge is uncertain, unpredictable, challengeable and contestable. In this context, universities should develop self-reliance in students, so they can prosper and act purposively in an uncertain and ever-changing world. Hence, contemporary education should foster abilities such as adapting to change; understanding phenomena in context; making connections between aspects that are not evidently linked; facing non-linear and ill-defined situations; and working in collaboration with others who may not share ideas or interests (Davis & Sumara, 2005, 2006; Frei, 2011). A complexity-based educational strategy allows addressing these needs, through the theoretical framework and methodologies that complexity science affords to support educational practices (Phelps, 2005; Davis & Sumara, 2006).

A complexity-based strategy for a game design course

In 2011 we adopted a complexity-based strategy to design and administer an undergraduate course in game design, delivered over one semester to 51 second-year computing students at the University of Worcester (UK).

Our first step was analysing salient aspects of the context of administration and delivery of the course, both exogenous (e.g. game design state of the art; employability requirements) and endogenous (e.g. university's strategic plan; student entry skills). As a result, we identified core educational objectives which the course should fulfil.

We then engaged in the design of the course, which was not fixed upfront. Rather, we defined and evolved it through iterative and adaptive design activities, based on evidence and events arising at key stages the course.

Through the adaptive design of the course we pursued the generation of conditions fostering the emergence of learning in educational CAS, mirrored by Davis & Sumara's (2006) model (Figure 1).

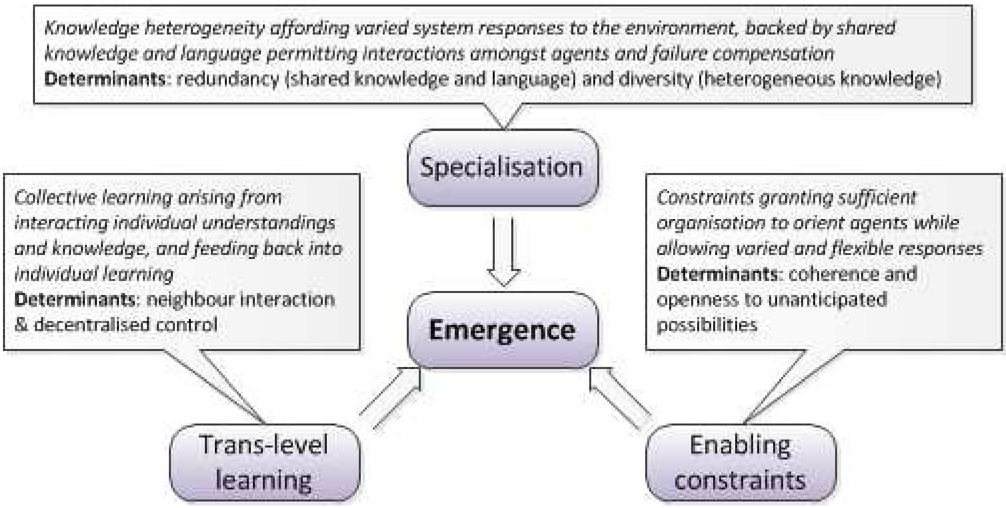

Figure 1

Accordingly, we aimed at: i) promoting specialisation, facilitating student shared knowledge development while at the same time nurturing diversity; ii) fostering trans-level learning, facilitating student interactions and promoting decentralised control; and iii) influencing course organisation and dynamics through enabling constraints, providing sources of disruption and randomness while maintaining coherence and focus.

In the following sections we describe core elements of the course designed through this strategy, highlighting key adaptations realised throughout the course development.

Learning activities

The course comprised both individual and collective activities. At the heart of the course was a collaborative, course-long project. Project workshops, lectures, collaborative formative tasks and individual learning journals complemented the project to facilitate learning. Starting from an initial plan, activities were defined and redefined as the course progressed, based upon evidence emerging from already-completed activities. This fostered system adaptive evolution and promoted trans-level learning through the interplay between individual and collaborative activities.

The **course project** aimed at engaging students in collaborative dynamics, requiring them to design an educational game for the Edward Elgar Birthplace Museum based on aims and specifications provided by museum representatives and tutors. The project was articulated in stages culminating in project milestones. There were three core milestones:

(1) Pitch, requiring an initial game concept compliant with the project requirements.
(2) Pre-production, requiring a preliminary design and proof of concept illustrating key game mechanics.
(3) Production, requiring the final game design, and a playable prototype implementing the core game features.

A fourth milestone (Post-production) was also planned, for finishing touches or late-minute fixes.

At each core milestone student teams were required to present the state of advancement of their project to a panel of evaluators including tutors and museum representatives. Evaluators assessed the outcomes providing independent, just-in-time summative and formative feedback, to facilitate further project work. Evaluation data was used to inform the (re)definition of learning activities.

Milestone deadlines were initially scheduled every three weeks. The project Production milestone was postponed by one week, to adjust to museum schedules.

Project Workshops allowed teams to receive support on their project work from independent consultants (academics and guest field experts). Preparatory and review workshops were held before and after project milestones, respectively.

Consultants “visited” teams if requested, and worked within constrained time slots, ensuring that all teams had access to consultancies. Consultants provided non-prescriptive, independent feedback, to reinforce/enhance good practices and identify risks (advisory feedback), and broaden students perspectives (exploratory feedback).

Lectures aimed at exploring contents and providing informative support to students. Tutors initially designed and planned a minimal set of lectures sufficient to cover the core contents, leaving scope to add further lectures to cover new topics and/or (re)explore core contents.

Four core lectures were planned at the beginning of the course. Three additional lectures were delivered based on emerging project outcomes. In total, lectures were present in only seven of the twelve course direct-contact sessions.

Formative tasks aimed at presenting to students problems closely related to what explored in the lectures, requiring them to conceive and discuss solutions.

Individual learning journals aimed at fostering the interplay of individual and collective learning, and student self-awareness. Students were required to compile a journal entry after each milestone, reflecting on specific aspects of their individual and collective learning experience. Entries comprised both open-ended items and structured items. Open-ended items required to reflect and apply knowledge and skills used for the milestones to analogous situations, and critically analyse milestone outcomes addressing issues through improvement proposals. These items were used for marking students. Structured items served to gather a detailed perspective on the whole learning experience, to inform iterative adaptations of the strategy. Hence, they were not marked and students were aware of this.

Course contents

Tutors involved in the course initially identified a core set of contents whose knowledge would be essential to pass the course. Tutors agreed that further contents would be added as the course unfolded, based on emerging evidence. Accordingly, pedagogical materials were planned to study core contents iteratively, through different means (e.g. books, videos, guided tours). Contents were broadened throughout the semester, to explore topics based on students' interests and the approaches they chose to develop their team projects.

Assessment

The course was assessed through a portfolio comprising the team project outcomes and the individual learning journal entries.

The **course project** was assessed by the panel of evaluators through public milestone presentations. Verbal feedback was provided to each team immediately after the milestone presentation. Feedback included the mark and a qualitative evaluation from each panel member, focused on project strengths and points of improvement. Teams were required to self-assess members' engagement in each project milestone. Students whose engagement was considered appropriate shared the team milestone mark. Otherwise, milestone contributions were assessed individually, granting only a percentage of the whole milestone team mark. The project mark was worth 65% of the final course mark.

Learning journals were submitted through an ad hoc web system, which was also used to provide just-in-time formative and summative feedback to students. The journal mark was worth 35% of the final course mark.

This portfolio, together with the workshops and formative activities described above, generate conditions defining learning environments that promote assessment for learning (McDowell et al, 2006), namely: using authentic and complex tasks, offering students formative and summative evaluations, providing rich formal and informal feedback, and developing evaluation of own progress and self-directed learning.

Complexity principles in the course implementation

Decentralised control and self-organization within teams

We decentralised control allowing teams to self-organise, thus facilitating the emergence of a decentralised student network, which is the best suited to foster specialisation and trans-level learning (Davis & Sumara, 2006; Newell, 2008). The project goals and requirements were intrinsically multidisciplinary and could be fulfilled through alternative solutions, none of which was discussed with students a priori. We wanted teams to freely define their approaches, with student roles and responsibilities emerging and reshaping through a student/team dialogic relationship, based on the student skills and interests, and on what the whole team considered to be appropriate to pursue the common interest. We expected all this to favour the emergence of both specialization and trans-level learning (Davis & Sumara, 2005, 2006; Newell, 2008).

Core knowledge and shared understandings

Core contents were the object of the shared understandings and the language necessary to permit fruitful and purposeful collaborative dynamics within each team and across teams, and interactions with consultants and tutors (Davis & Sumara 2005, 2006).

Support for heterogeneity in learning

The adoption of redundant and heterogeneous pedagogical materials was aimed at supporting different learning styles (Mainemelis et al., 2002), thus promoting heterogeneity among students and fostering the emergence of specialisation (Davis & Sumara, 2006; Newell, 2008).

Perturbations triggering adaptive dynamics

Advice from consultants, evaluations and project requirements were exploited to expose students to frequent and often unexpected perturbations, requiring teams to continuously adapt to a dynamic context.

Consultants provided advice which was never prescriptive, and aimed at scaffolding team learning, acting as enabling constraints (Davis & Sumara, 2006). As consultant advice was independently provided and reflected consultants' heterogeneous perspectives, student teams had the final responsibility as to what to accept and how to synthesise sometime divergent recommendations.

Project requirements implicitly promoted collaborative dynamics through a workload that was hardly affordable without appropriate team organisation. Requirements were never prescriptive, specifying objectives but not ways to achieve them. Furthermore, frequent moderate changes in project specifications required teams to adapt their approaches on a regular basis.

Relevance and feasibility of contents

To promote meaningfulness and relevance, core contents were selected based on exogenous contextual factors (e.g. industry state of the art; employability requirements). At the same time we took into account important endogenous factors (e.g. time constraints) to safeguard feasibility.

Iterative and incremental teaching

Learning activities were organised to iteratively study and apply concepts and frameworks at different levels of depth, complexity and integration. This aimed at promoting the redefinition of ideas and concepts at increasingly sophisticated levels through a spiral process, requiring to learners '(…) a continual deepening of one's understandings of them [ideas and concepts] that comes from learning to use them in progressively more complex forms.' (Bruner, 1999, p. 13)

Assessment portfolio as a facilitator of specialisation

A portfolio comprising a multi-disciplinary self-organised project was deemed appropriate to both assess standard skills and promote the development of emerging skills (Frei, 2011). We planned the portfolio to foster skill heterogeneity and allow students to specialise and develop along diversified paths, decentralising control and allowing team self-organisation to make specialisation possible (Davis & Sumara, 2006; Newell, 2008).

Assessment as a "window onto the system"

Assessment activities were planned to generate a constant flow of information regarding system dynamics, necessary for tutors to adapt the course based upon emerging events.

Evaluating the impacts

Participants

51 students were enrolled in the "Foundations of Game Design" course, delivered in the academic year 2011/2012. Three tutors were involved in the course, exercising different roles according to their professional backgrounds.

Evaluation rationale and instruments

From a complexity perspective, impact is seen as a process of change that is adaptive in nature. This means that whole processes, not only outcomes, should be examined, trying to understand how individuals continuously interact with their context, and how this leads to knowledge production at micro and macro levels (Davis & Sumara, 2005). Hence, we analysed the outcomes of milestones and journal entries submitted in association to each milestone, and data regarding the whole learning experience provided by students through the structured items comprised in each journal entry.

Structured journal items (not marked) were designed to explore the students' opinions, feelings and perceptions regarding:

- Teamwork.
- Project activities (level of difficulty, relevance to the module, perceived quality of performance, motivation, enjoyment).
- Progress and expertise, defined by feelings of autonomy and development of abilities and confidence with the course topics.

Performance in learning journal outcomes was assessed through open-ended items in journal entries, and weremarked by an evaluator.

Performance in project outcomes was accounted for through the milestone evaluations. These were assigned by a panel of evaluators after each project milestone presentation.

Marked and non-marked evaluations were expressed on a 5-point scale. Although scale statements varied depending on the item content, they all followed the same structure (1=lowest value; 5= greatest value).

In all cases, averages were calculated to summarise the main trends found in the course at each milestone. Averages were classified in qualitative ranges to interpret the results:

- Below 2: Very Poor (or Very easy, or Not at all, etc.)
- From 2 to 2.69: Poor (or Easy, Very little, etc.)
- From 2.6 to 3.19: Fair (or Neither easy nor difficult, Neutral, etc.)
- From 3.2 to 3.99: Good (or Difficult, Somewhat, etc.)
- From 4 and above: Very Good (or Very difficult, Absolutely, etc.)

Results

Evolution of teamwork

There was a surprising difference between the evolution patterns of the different aspects of the work done by teams (Figure 2). Teams initially perceived that their ability to agree on key decisions regarding their projects was Very Good, and this perception remained constant for the next milestones. Collaborative problem-solving and team communication were initially perceived by students as Good, and increased to Very Good as students approached the Production milestone. This did not happen with the other teamwork aspects. On average, workload distribution was always perceived as Good, showing some fluctuations between milestones, but never increasing or decreasing excessively. Time management skills presented the greatest variation throughout the course. In the beginning students had some difficulties in organising their time to work in groups and reconcile the course demands with their other academic activities. Good time management was achieved after the first milestone, remaining constant for the rest of the course.

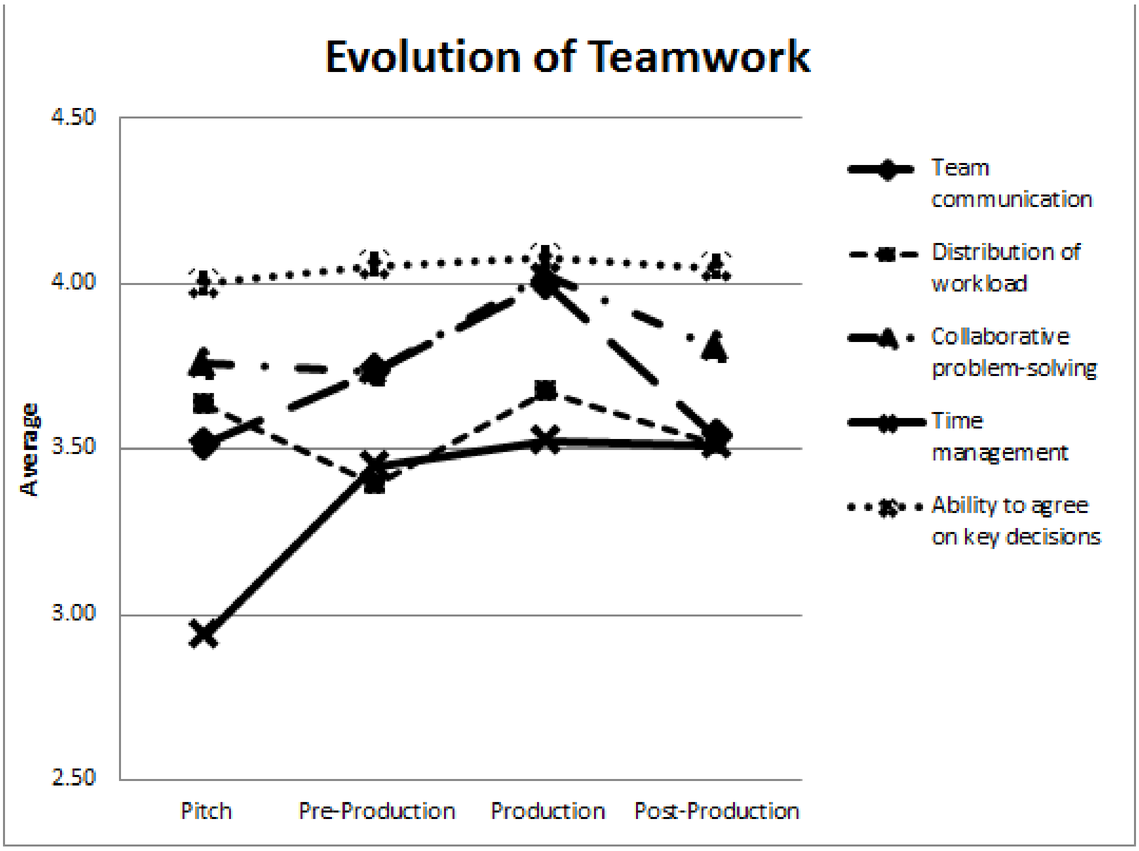

Figure 2

Team communication, collaborative problem-solving, time management and ability to agree on key decisions were correlated to the team performance (r=0.25, r=0.24, r=0.28, r=0.22 respectively). Interestingly, no correlations were found between the outcomes of milestone teamwork and the individual journal entry scores obtained by students in each milestone. These results are coherent with the literature indicating that participatory, collective, and on-going engagement enables the emergence of collective cognition and knowledge production in processes of adaptation to requirements and constrains of dynamic and uncertain contexts (Davis & Sumara, 2006; Newell, 2008). Results also corroborate that the emergent collective generates insights that surpass those of any individual member (Davis & Sumara, 2006), and that discussion plays an active role in the creation and improvement of knowledge when it is oriented towards a collective understanding (Jordan, 2010).

Team performance dropped somewhat at the post-production milestone, and so did some key aspects of teamwork (e.g. collaborative problem-solving). The last milestone was a ‘fix/enhancement’ opportunity through which teams could improve their project. Because of the assessment strategy, a lower mark in this milestone would only marginally affect the overall evaluation of the project. Hence, teams who secured a good result through the former milestones may have felt that no further significant efforts were required, deciding to devote more time to other academic activities instead.

Perception of project activities

Project activities were considered by students relevant to better understand the topics of the course (Figure 3). In general, students perceived an almost ever-increasing level of difficulty. The Pitch was mostly perceived as neutral (Neither easy nor difficult). Perceived difficulty increased until the Production milestone, which was mainly considered as Difficult. ‘Despite’ (or perhaps ‘because of’) the progressive increase in milestones’ difficulty, from the beginning students felt very motivated to work on the learning activities. Most students found the activities challenging, motivating, relevant to their learning and enjoyable to perform. Thus, it is not surprising that the level of enjoyment reported by the students was very high as well, and stable across the different activities.

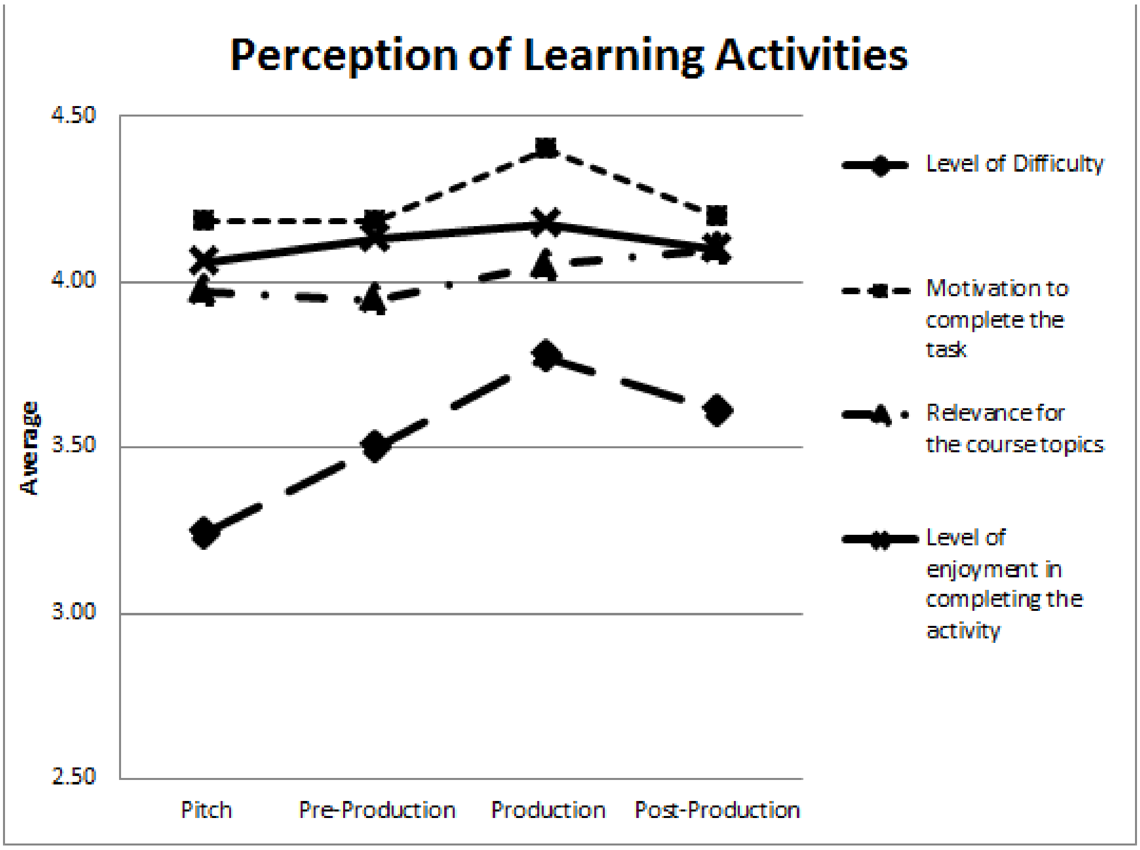

Figure 3

Perception of progress and expertise

Students perceived that they were improving the abilities required to deal with the topics of the course and that they were gaining more confidence. These perceptions were reported from the beginning of the course and evolved positively during the semester.

Regarding the perception of expertise, from the beginning students rated as 'Good' their level of understanding of the course topics and confidence in successfully accomplishing project tasks related to the topics previously studied, working both in teams and autonomously. Self-perceived level of understanding remained constant throughout the course, while confidence increased slightly.

Evident differences appeared between the perceived performance in the course and the scores assigned by evaluators to team and individual work (Figure 4). According to evaluators' assessments, average team performance was Fair in the pitch and rapidly increased to Good in the following milestones. Average individual scores always remained in the Good category. Interestingly, team scores increased over time to level up with the individual scores.

As to the discrepancy between perceived performance and evaluators' assessments, it is possible that the students initially perceived that their individual work was sufficient to produce good team results. After realising that their performance was not as good as expected, students probably recognised that they needed to work more and better with their teams, enhancing interactions and producing more collective knowledge. Team self-organisation is not automatic, especially when students are not used to work in teams and face complex group dynamics. Time and continuity of interaction is needed in order to create the clashes of ideas and the interplay of individual and collective learning which lead to the emergence of team knowledge that transcends the sum of the student individual knowledge (Newell, 2008).

Insert Figure 4 near here

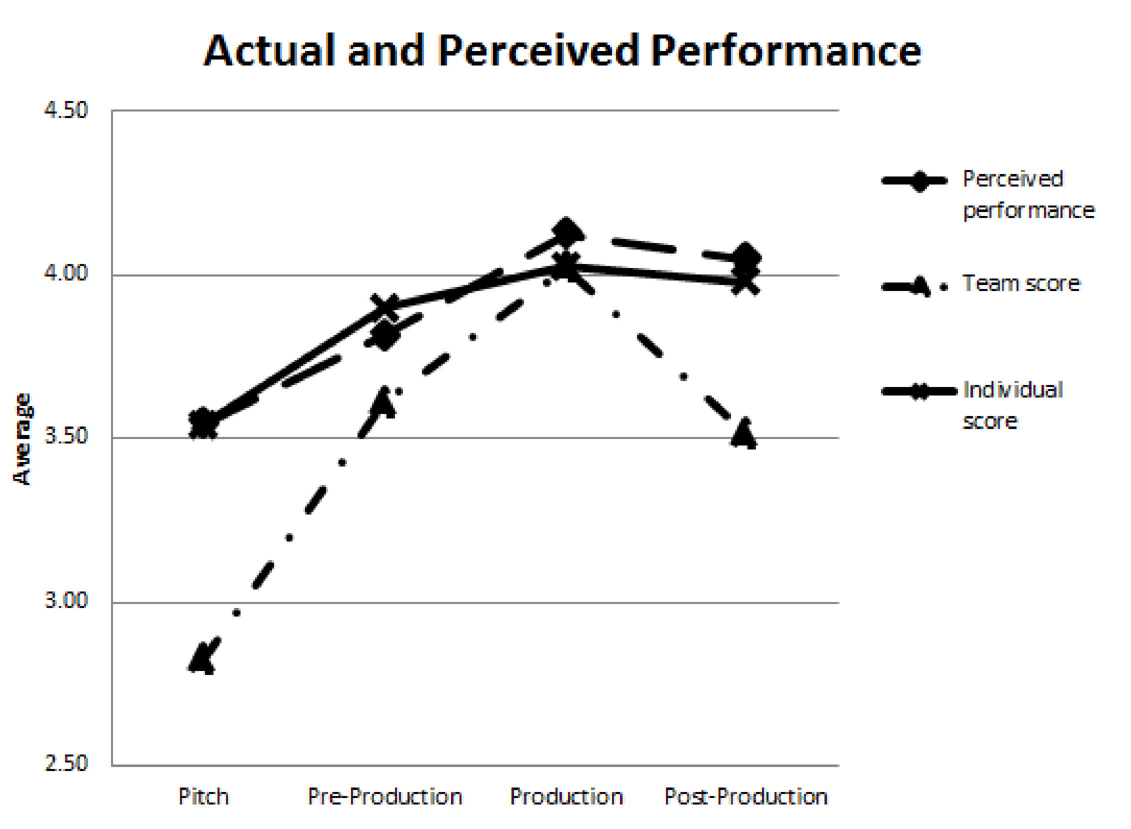

Figure 4

Conclusions

This paper reports an experience in a higher education course developed and managed through a complexity-based educational strategy. Examining the course through the lens of complexity, we focused on different processes at different levels, in different moments and involving different actors. Through this approach to evaluation we could follow students' progress, and also monitor if/how the course organisation and activities enabled student engagement in complex dynamics and fostered emergent learning. This ability to iteratively monitor the course evolution was key to our complexity-based strategy, as it permitted to acknowledge emergent dynamics and adapt the course accordingly.

We believe that engagement in challenges and situations driven by dynamics of complexity is key to promote the development of mindsets able to cope with complexity. Adaptation to change and self-organisation cannot be learned without being part(icipants) of situations that require them. It is therefore paramount that educators willing to support the development of complexivist mindsets be acquainted with types of educational activities which prompt students to face complex dynamics. In our experience, we witnessed how students had to deal with complex situations and how they managed to self-organise their work. Likewise, we also witnessed our own transformational processes, which demanded us to adapt and change our plans, even revising our assumptions regarding key aspects of the course.

This study suggests that designing a course based on complexity science can be highly beneficial, since the way in which activities were structured and defined required students to face complex dynamics and self-organize within teams. It was interesting to see how teamwork skills evolved throughout the course, and how they were related to the learning produced by teams as collective entities. As Jordan (2010) indicates, individual and collective learning are a consequence of the interactions of connected and diverse agents. Both individual and team scores increased as students continued to work collaboratively in teams through the different milestones, but it was team scores that presented the greatest improvement throughout the semester.

We were surprised to see that, from the beginning, students in general gave high ratings to their motivation, learning and progress, in spite of the increasingly high challenges that they faced. The evidence we have analysed suggests that an iterative and adaptive strategy allows constantly promoting students' feeling of increasing their abilities and understanding of the topics of the module. It also fosters the idea of being able to accomplish required tasks either autonomously or with a team.

While our understanding of the role of complexity in education continues to grow, our efforts are strongly motivated by the potential of complexity-based strategies to prepare individuals to face the complex problems that characterise our world. To this end, we recommend further study into the practices that may foster the emergence of collective knowledge, and how these may be promoted by the broader educational context in which they operate.

Notes on contributors

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Ximena López is an educational psychologist with research interests in the areas of technology and education, game-based learning, mobile learning, CSCL and disabilities. She holds a Ph.D. in educational psychology and currently collaborates with diverse higher education institutions in Chile, Italy, USA and UK.

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